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Comparing silvicultural alternatives for restoring western white pine in the North Fork Clearwater River Basin, Idaho

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COMPARING SILVICULTURAL ALTERNATIVES FOR RESTORING WESTERN WHITE PINE IN THE NORTH FORK CLEARWATER RIVER BASIN, IDAHO.

by

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Comparing Silvicultural Alternatives for Restoring Western White Pine in the North Fork Clearwater River Basin, Idaho

Chair: Carl Fiedler CF

Two silvicultural prescriptions were developed to restore western white pine (*Pinus monticola*) in the North Fork Clearwater River Basin of northern Idaho. The first prescription reduced the overstory basal area to 35 ft.^{2} per acre, and the second to 75 ft.^{2} per acre, to approximate visible sky levels that give western white pine free-to-grow status and competitive advantage over grand fir (*Abies grandis*) and western hemlock (*Tsuga heterophylla*). The prescriptions were modeled using the Forest Vegetation Simulator. Cutting treatments were followed by planting 200 F_2 western white pine seedlings and 200 western larch seedlings per acre. Twenty years after treatment, the planted western white pine and western larch showed greater height and diameter growth than naturally regenerating species for both prescriptions, but naturally regenerating species had greater density. The 35 ft.^{2} prescription resulted in greater height and diameter growth for western white pine than the 75 ft.^{2} prescription. Under the 35 ft.^{2} prescription, western white pine averaged 119 trees per acre with an average height of 20.2 feet and an average diameter of 3.0 inches twenty years after treatment. The 75 ft.^{2} prescription averaged 89 western white pine per acre with an average height of 15.9 feet and an average diameter of 2.3 inches. Using a skyline yarding system with an average yarding distance of 1800 feet and 100-mile haul to a mill yielded net returns of $1,255 per acre for the 35 ft.^{2} prescription and $757 per acre for the 75 ft.^{2} prescription. With a 200-mile haul, net returns dropped to -$249 per acre for the 35 ft.^{2} prescription and -$355 per acre for the 75 ft.^{2} prescription. Although the treatments provide an initial advantage for western white pine and western larch, treatments such as cleaning will be necessary to control species composition in the future and ensure that the planted species will be featured in the stand at maturity. Field testing of these prescriptions is needed to confirm modeled results, and further analysis is needed to determine their applicability to other areas in the Inland Northwest where restoring western white pine is a management objective.

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TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

INTRODUCTION

Early in the 20th Century, widespread and intense forest fires in northern Idaho created extensive areas of early successional forests. As the forests recovered from the wildfires and fire suppression capabilities improved, species composition shifted from early successional, shade-intolerant species to mid-successional, shade-tolerant species. In addition, white pine blister rust (*Cronartium ribicola*), a non-native disease affecting five-needle pines, decimated the remaining western white pine (*Pinus monticola*) trees throughout the region. The shift in species composition has also increased the forest's susceptibility to insect and disease outbreaks.

In the late 1990s, the Clearwater National Forest, as part of a collaborative effort among many groups in response to concern about the area's declining elk population, conducted an assessment of 840,000 acres of federal land on the Forest's North Fork Ranger District. The assessment, known as BHROWS (Big Game Habitat Restoration On a Watershed Scale), evaluated vegetation, soils and geology, wildlife and fisheries, and hydrology in the 21 watersheds found in the North Fork Ranger District. Included in the assessment was a characterization of how the ecosystems had changed, as well as preliminary recommendations for addressing those changes. Historically, early successional stages occupied 35-45% of the area; today, only 14% of the area is currently occupied by those stages. Mixed conifer forests of western white pine, western larch (*Larix occidentalis*), and ponderosa pine (*Pinus ponderosa*) were once common; these have now been replaced by stands of Douglas-fir (*Pseudotsuga menziesii*), grand fir (*Abies grandis*), and lodgepole pine (*Pinus contorta*). Of particular importance is the decrease in western white pine caused by the white pine blister rust fungus. The major recommendation of the assessment was that treatments are necessary to restore the forest structure and species composition that existed prior to the large fires of the early 1900's and the concurrent arrival of white pine blister rust (CNF 1999).

The BHROWS assessment characterized the need for restoration and prioritized restoration treatments in each of the 21 watersheds in the North Fork Ranger District. The Middle North Fork Clearwater River and Upper North Fork Clearwater River (Kelly Creek to Long Creek) watersheds, collectively known as the Middle North Fork--Black Canyon area and hereafter referred to as the Middle-Black area, were identified as the two watersheds most in need of restoration treatment. A draft environmental impact statement (DEIS) called the Middle-Black Analysis proposed, described, and evaluated five alternative treatments that could be implemented as a means of accomplishing restoration.

Restoration is defined as "the process of returning ecosystems or habitats to their original structure and species composition" or "the removal of nonhistorical elements from a historic structure and the replacement of any missing elements" (Helms 1998). Restoring the natural processes inherent to a specific ecosystem is a key component and objective of restoration; simply removing nonhistorical elements and recreating original structure and species composition does not guarantee that the ecosystem will be able to sustain itself following a restoration treatment. This thought is reflected, though not explicitly, in The Society for Ecological Restoration International's (SER) definition of ecological restoration: "the process of assisting the recovery of an ecosystem that has been degraded, damaged, or destroyed" (SER 2004). Undertaking and accomplishing restoration activities in the Middle-Black area is no small challenge, but the process can be initiated by re-introducing fire to these forests, applying silvicultural cutting treatments, or a combination of both. The Middle-Black DEIS includes four different combinations of these activities.

Restoration efforts should not simply focus on one component of the area's ecosystems, but on all components. Among the purposes listed for taking action in the Middle-Black area are restoring a distribution of successional stages that more closely resembles that found in the area prior to fire suppression, restoring western white pine, western larch, and ponderosa pine that once dominated the area's forests, and reducing the percentage of shade-tolerant species such as Douglas-fir and grand fir that now cover a large portion of the area (CNF 2001).

Forest restoration in the Middle-Black area presents many challenges. Foremost among these is the relative lack of a natural seed source for restoring western white pine and the presence of white pine blister rust. These factors imply that artificial means will have to be used to regenerate the stands following treatment in order to alter the species composition of the future stand. Genetically improved western white pine planting stock that is resistant to the white pine blister rust fungus is available for planting, although the degree of resistance varies (Fins et al. 2002). Furthermore, the conditions of the stand following treatment must be favorable for the planted stock to establish and out-compete naturally regenerating species.

Additionally, much of the analysis area is remote and has steep terrain, and access by roads to the analysis area is limited. These factors limit operability in terms of timber harvesting, which is one of the proposed tools for accomplishing restoration treatments.

Yarding systems using helicopters and/or aerial cable (skyline) systems would likely be needed to harvest timber in these areas. These systems tend to be expensive to operate. This is a major concern, as the value of the timber removed during harvesting operations may be used to help offset the costs of restoration (Fiedler et al. 1999).

Prior to undertaking any restoration activities, forest managers must realize that multiple treatments will likely be necessary to accomplish the goal of restoring western white pine forests. The first step of restoration is to re-establish a rust-resistant western white pine seed source on the landscape. In order to accomplish this, forest managers must consider the following questions:

1. What silvicultural prescriptions will create conditions that allow planted western white pine and western larch to out-compete naturally regenerating species?
2. What will the future stands look like?
3. How much will it cost to implement the first step of restoration?

The long-term goal of this study is to provide forest managers throughout north-central Idaho with a set of ecologically based and financially feasible silvicultural alternatives to assist them in implementing restoration of western white pine forests, and provide an estimate of the costs associated with implementing the prescriptions. The specific objectives of this study are to:

- Develop alternative silvicultural prescriptions for treating mid and late-seral stands of Douglas-fir and grand fir as the first step in restoring mixed conifer forests of western white pine and western larch.
- Evaluate effectiveness of the prescriptions in terms of the resulting future stands.
- Determine the value of timber as a by-product of restoration treatments.

- Assess the economic feasibility of using various yarding systems associated with the treatments.

The silvicultural alternatives developed and analyzed for this study will include regeneration treatments designed to provide the necessary conditions to re-establish western white pine and western larch. Differences between treatments are expected in the growth of western white pine and western larch, species composition of the future stands, cost of harvesting operations, and the value of timber produced as a by-product of restoration.

LITERATURE REVIEW

Ecology of western white pine

Western white pine is a five-needle pine found in three forest regions in the western United States and British Columbia. It grows in the coastal region of British Columbia and south through the Cascade Range of Washington and Oregon; it is also found in the Sierra Nevada and Siskiyou Mountains of California (Little 1971). However, its most important range is the Inland Northwest (Graham 1990), which includes northern Idaho and portions of northeastern Washington, western Montana, and southeastern British Columbia (Little 1971). In this region, it is typically found between 1600 feet and 6000 feet, and prefers creek bottoms and associated low benches, moist mountain slopes, and north-facing aspects (Graham 1990).

Common tree species associated with western white pine in the Inland Northwest include grand fir, subalpine fir (*Abies lasiocarpa*), Douglas-fir, western redcedar (*Thuja plicata*), western hemlock (*Tsuga heterophylla*), mountain hemlock (*Tsuga mertensiana*), western larch, ponderosa pine, lodgepole pine, Engelmann spruce (*Picea engelmannii*), and paper birch (*Betula papyrifera*) (Boyd 1980). Western white pine occurs primarily in even-aged stands where it may share the overstory with other shade-intolerants, such as western larch and lodgepole pine. Shade-tolerant species such as grand fir, western redcedar, and western hemlock typically occupy the understory (Boyd 1980). These even-aged stands are typically the result of stand-replacing wildfires or even-aged silvicultural practices (Boyd 1980, Graham 1990).

Western white pine was historically dependent on fire to prepare sites where the trees could establish. Stand-replacing fires created openings that provided white pine with favorable conditions to establish and grow (Fins et al. 2001). White pine's tall stature among its associates and lightweight, wind-borne seeds allowed it to easily establish in new openings created by wildfires (Neuenschwander et al. 1999).

Western white pine is one of the fastest-growing conifers in the Inland Northwest, though early growth is not rapid until seedlings have become established. Western white pine's shade tolerance is classified as intermediate; it can establish under partial shade but prefers full sunlight once it is established (Haig et al. 1941). Only lodgepole pine and western larch have growth rates that match or exceed western white pine in full or nearly full sunlight conditions (Haig et al. 1941). Under partial shade, grand fir and western hemlock can match the growth of western white pine (Haig et al. 1941). The growth rate of western white pine is variable, with growth of 20-year old western white pine on poor sites as low as 9 inches per year or as high as 39 inches per year on good sites (Graham 1990). At 20 years of age, western white pine varies from 10 feet tall on poor sites (site index 40, base age 50 years) to 20 feet on good sites (site index 70+, base age 50) (Haig 1932). Dominant and codominant western white pine in fully stocked stands on high quality sites (site index 80) may reach heights averaging 175 feet (Haig 1932, Graham 1990).

Western white pine can begin producing cones as early as age 7, but cone and seed production become prolific at age 70 and generally increase with age until the tree is fully mature (Haig et al. 1941). Seedfall begins in the fall and is mostly completed by the end of October. Most seed is dispersed by wind. Seeds require a cold dormancy period of 30 to 120 days prior to germination. Western white pine does not reproduce vegetatively (Graham 1990).

White pine blister rust is the most important disease affecting western white pine. Western white pine is also prone to an assortment of root rots, such as *Armillaria* spp., *Heterobasidion annosum*, and *Phellinus weiri*. Butt rot fungi such as *Phellinus pini* and *Phaeolus schweinitzii* also affect western white pine. Western white pine can also be affected by pole and needle blights caused by various agents (Graham 1990).

The mountain pine beetle (*Dendroctonus ponderosae*) is the most important insect affecting western white pine. It attacks weakened mature groups of trees, principally those weakened by white pine blister rust (Graham 1990).

Silviculture of western white pine

Whereas many of the traditional silvicultural methods and management of forests in the western white pine type focused on timber production, a new focus on non-timber values and ecosystem management is causing forest managers to re-evaluate the role of silviculture in western white pine forests (Graham et al. 1994). The focus on ecosystem management shifts the emphasis of management from the stand to the broader ecosystem as a whole (Jolly 1994). Traditional silvicultural techniques that were applied at the stand level will continue to be applied in the western white pine type, though in a broader context than simply for timber production (Graham et al. 1994). The challenge for forest managers in the western white pine type is to integrate and adapt traditional silvicultural techniques in a manner that addresses ecosystem function (Graham et al. 1994), as well as to develop new techniques as new information about the function of western white pine ecosystems is gathered (Jolly 1994).

Regeneration treatments

Because of western white pine's dependence on wildfire, even-aged silvicultural systems have typically been used to manage forests in the white pine type. Uneven-aged systems have been used sparingly in western white pine forests, although the group selection method may be a viable alternative for uneven-aged management. New management regimes are also being developed. Intermediate treatments are useful for regulating density and species composition, or improving stand quality and value.

Historically, even-aged regimes—clearcutting, seed tree, and shelterwood—provided adequate regeneration in the presence of an adequate seed source; however, the applicability of each method is not interchangeable among stands in the western white pine type (Boyd 1969). Rather, managers should carefully evaluate all factors affecting a stand's management before choosing a silvicultural system (Haig et al. 1941, Boyd 1969).

Clearcutting involves the removal of the overstory during a single entry into the stand, although narrow uncut strips or blocks may be left to serve as a seed source (Haig et al. 1941) or to provide a degree of protection for the stand (Graham et al. 1983). It is the easiest method to apply in the western white pine type (Graham et al. 1983), and it approximates the stand-replacing fires that white pine requires to perpetuate (Haig et al. 1941). Clearcutting is best applied on less exposed slopes, particularly those that are north- or east-facing, as these aspects are typically more protected than south-facing and some west-facing aspects (Haig et al. 1941). On these sites, western white pine can readily establish and competes favorably compared to its associates (Haig et al. 1941). When clearcutting has been applied on more severe aspects and slopes, difficulty regenerating the stand has been repeatedly observed (Haig et al. 1941). In most cases this is due to competition from dense brush or animal damage (Graham et al. 1983). Clearcutting relies on adjacent stands or uncut strips or blocks within the stand as a seed source (Haig et al. 1941); thus, the size of the clearcut patch impacts the success of naturally regenerating the stand. Large patches may not regenerate adequately because wind-borne seed may not be carried to all areas of the clearcut; therefore, Haig et al. (1941) recommend that all areas of a clearcut are within 200-400 feet of a seed source. However, clearcutting lends itself well to planting following harvest, particularly if species-conversion is a management objective (Graham et al. 1983). Stands on protected sites can be expected to regenerate within 10 years following treatment (Haig et al. 1941). Another advantage of clearcutting is that slash disposal is relatively easy through the use of broadcast burning or mechanical means on less steep sites (Graham et al. 1983). With broadcast burning there is a significant risk that the fire may burn too hot and damage the soil; because of this planting is typically necessary following burning (Haig et al. 1941). Despite the success of clearcutting in creating naturally regenerated stands in western white pine forests, negative public sentiments regarding clearcutting (Bliss 2000) make it unlikely that this method will be widely used.

The seed tree method produces similar results as clearcutting in western white pine forests (Haig et al. 1941), but is differentiated from clearcutting by the presence of scattered seed trees that are left in the stand following harvest. One advantage of the seed tree method compared to clearcutting is the ability to exhibit some control over the species composition of the stand because the remaining seed trees are relied upon as the principal means for regenerating the site (Haig et al. 1941), although adjacent stands will have some influence. Seed trees should be dominants or codominants, prolific seed and flower producers with good vigor, form, and wind-firmness (Haig et al. 1941, Nyland 1996). Such trees are among the best trees growing in a stand and serve as a good genetic source for the future stand, increasing the chance that regenerated trees will have the aforementioned desirable characteristics (Nyland 1996). Two to six western white pine trees per acre are recommended, with a few additional western larch or Douglas-fir seed trees left, if available (Haig et al. 1941). Like clearcutting, the seed tree method is best applied on northerly and easterly aspects, as well as flat areas (Haig et al. 1941). Following harvest, Graham et al. (1983) recommend the prompt removal of seed trees following regeneration; however, Haig et al. (1941) state that the removal of seed trees is not silviculturally necessary. Regeneration takes from one to ten years using the seed tree system in western white pine forests (Haig et al. 1941).

The shelterwood system differs from clearcutting and the seed tree system by leaving a moderate residual overstory, or overwood, that is relied on as a seed source, as well as to provide protection for the regenerating stand (Nyland 1996). It further differs from the seed tree system by specifying the removal of the overwood after the regenerating trees have reached sufficient size and density (Nyland 1996); this overstory removal is optional when using the seed tree method (Haig et al. 1941). The shelterwood system is generally applied over two or three separate entries in the stand. An optional entry known as a preparatory cut may be needed prior to the seed cut to promote the vigor and seed production of potential overwood trees (Nyland 1996). The seed cutting removes the overstory with the exception of trees left to provide seed and protection (overwood). The removal cutting removes the overwood to allow the newly regenerating trees uninhibited growth potential. The characteristics of overwood trees are similar to those of seed trees in the seed tree system: good vigor, form, and seed production (Nyland 1996). The density of the overwood varies depending on environmental factors and silvicultural objectives (Nyland 1996), making the shelterwood system one of the most flexible even-aged systems, particularly in the western white pine type (Haig et al. 1941). An overwood density of 15 to 40 trees/acre is recommended (Graham et al. 1983), with fewer trees on more protected sites (Haig et al. 1941; Graham et al. 1983). The density of the overwood, when compared to alternative even-aged systems, makes the shelterwood system appropriate for use on more exposed sites, such as southerly aspects or steep slopes (Haig et al. 1941, Graham et al. 1983). The shelterwood system also has a longer regeneration period than the clearcutting or the seed tree system; stands treated under the shelterwood system in Boyd's (1969) case studies at Deception Creek Experimental Forest had regeneration periods ranging from four to over 20 years to reach 80 percent stocking. One disadvantage of the shelterwood system is that the density of the overwood promotes the development of shade-tolerant species, which can be detrimental when managing for western white pine (Haig et al. 1941). Boyd's (1969) studies at Deception Creek showed that shade-tolerants can dominate regeneration in a stand regenerated using the shelterwood system, even if no shade-tolerants were left in the overwood. However, intermediate treatments can be used to adjust the species composition and density of the regenerating stand (Graham et al. 1983), as is true with any of the even-aged methods.

Uneven-aged management regimes have not been applied extensively in the western white pine type. These systems are not particularly well-suited for the even-aged forests typical of the western white pine type (Graham et al. 1983). In addition, uneven-aged systems are generally more difficult to apply and regulate than even-aged methods, and are usually more expensive to apply (Graham et al. 1983, Graham and Smith 1983). The individual tree selection method tends to favor shade-tolerant species (Haig et al. 1941, Graham and Smith 1983), making it a poor choice when managing for western white pine. In contrast, the group selection method, although not applied extensively in western white pine forests, shows some promise for successfully regenerating seral species in an uneven-aged regime (Graham et al. 1983, Smith and Smith 1994).

Group selection involves removing small groups of trees within a stand to create openings for regeneration. The key advantage that group selection exhibits over individual tree selection with respect to the success of regenerating seral species is that more light is permitted to reach the forest floor because the openings created by group selection are larger than those created by individual tree selection (Smith and Smith 1994). Generally speaking, the smaller the opening the greater the proportion of shade-tolerant species in the regenerating stand (Graham et al. 1983); however, openings ranging from 0.25 to 1.25 acres will provide enough light for seral species to regenerate (Smith and Smith 1994). The openings created by group selection are also suitable for planting improved stock, if necessary (Graham et al. 1983). Another advantage of group selection is the maintenance of forest cover in the stand, which addresses visual concerns of harvesting and maintains aesthetic values in the stand (Smith and Smith 1994).

Recent research has also resulted in new silvicultural applications in western white pine forests. Jain et al. (2004) studied the impact of canopy cover relative to western white pine growth and identified threshold levels for western white pine to occupy a site (> 23 percent visible sky), exhibit a competitive advantage over western hemlock and grand fir (> 50 percent visible sky), and achieve free-to-grow status (> 92 percent visible sky). Traditional density measures tend to correlate poorly with visible sky (Jain et al. 2004), but may be useful for field foresters attempting to create conditions similar to the described visible sky thresholds.

Intermediate treatments

Intermediate treatments are commonly used in the western white pine type. These may include early release treatments, thinning, or improvement cutting.

Early release treatments should be applied in the first 30 years following regeneration, as this is the time period that determines the species composition and growth rates of the regenerating stand (Haig et al. 1941, Graham 1988). Additionally, after the stand has reached age 30, heavy thinning is necessary to gain a lasting benefit in terms of response, and this comes at the expense of previous growth and yield that cannot be recaptured (Deitschman 1966).

Cleaning is the most common early release treatment applied in western white pine forests. It increases the proportion of white pine in a stand, as well as the height and diameter growth of dominant trees. Wellner (1940, 1946), Boyd (1959), and Deitschman and Pfister (1973) illustrated this by reporting the results over a 30-year period of a cleaning study established in the Priest River drainage in Idaho. Wellner (1940, 1946) described the early advantage that western white pine attains over associated species when favored in a cleaning, as well as the ability of a cleaning to alter species composition to favor white pine. Boyd (1959) and Deitschman and Pfister (1973) showed that the effects of the cleaning extended beyond the sapling stage and increased the height and diameter growth of western white pine, allowing it to attain a dominant position in the stand. Studies on Deception Creek Experimental Forest (Boyd 1959, Deitschman and Pfister 1973) supported the results of the Priest River study.

The intensity of a cleaning impacts the proportion of western white pine, height, and diameter growth that may be achieved following treatment. Deitschman and Pfister (1973) found that where two levels of cleaning were tested, the heavier cleaning resulted in the greatest proportion of western white pine, as well as the greatest height and diameter growth. Conversely, in the uncleaned check plots, western white pine was nearly absent from the stand after 30 years. Deitschman and Pfister (1973) also found that the long-term impacts on species composition are only realized when the favored species in a cleaning is able to retain the advantage provided by the treatment. If the cleaning is performed too early in a stand's life, the advantage given to the favored trees may be short-lived. Favored trees may not have reached sufficient size to express dominance over new trees that may enter the stand, and their crowns may not close quickly enough to prevent fast-growing, shade-intolerant species from overtaking them. The latter may be especially apparent in heavier cleanings, where the crowns of the trees favored during the treatment will take a longer time period to shade the area and effectively reduce the ability of potential new trees to compete.

Thinning benefits stands containing western white pine by improving stand and tree quality, but does not significantly increase volume production (Graham 1988). Diameter growth for western white pine following thinning is related to the intensity of the thinning: more intense thinnings produce a greater response in diameter growth (Graham 1988). Several studies illustrate these statements. Foiles (1956) studied the effects of multiple thinnings in a 55-year-old stand containing western white pine and found that volume production did not increase in thinned plots compared to an unthinned check plot. He concluded that although the thinnings did stimulate diameter growth, it was not at a rate that was appreciably different from the trees on the unthinned check plots. Deitschman (1966) studied three levels of thinning from above and thinning from below and found that thinnings removing half of the basal area provided the greatest response in diameter growth, but even at this level the response was not aggressive. Foiles (1972) studied the effects of crown and selection thinning in an 87-year-old mixed stand of grand fir and western white pine. Grand fir had a greater treatment response than white pine in terms of diameter growth for all treatments, presumably because it retains a fuller crown than western white pine and is better able to take advantage of the growing space provided by thinning treatments. Light crown thinning (removing 20 percent of the stand's volume) provided the best response in terms of net growth following treatment; however, the level of growth achieved with the light crown thinning was less than on the control plot. Moderate crown thinning (removing 35 percent of the stand's volume) resulted in the least mortality per acre following thinning. Selection thinnings, particularly at the higher removal level (35 percent volume removed), are generally not recommended due to higher losses to mortality following treatment. The selection thinning removed the most vigorous trees from the stand, leaving less vigorous trees that were more susceptible to injury and mortality.

White pine blister rust

White pine blister rust has been the most damaging agent in western white pine ecosystems in northern Idaho (Atkins et al. 1999; Fins et al. 2001). The disease is caused by a non-native fungus that was introduced to the Northwest in 1910 on infected stock grown in France and planted near Vancouver, British Columbia (Hagle et al. 1989, Atkins et al. 1999). It was first seen in Idaho in 1927 (Hoff et al. 1976, Atkins et al. 1999) and reached epidemic levels in the 1940s (Atkins et al. 1999, Fins et al. 2001).

Control efforts

The first efforts to control white pine blister rust focused on eradicating gooseberry (*Ribes* spp.), the alternate host, in order to disrupt the life cycle of the fungus (Ketcham et al. 1968, Hagle et al. 1989). Managers focused their efforts on eradicating *Ribes* in and around the most productive or valuable white pine stands (Ketcham et al. 1968, Hagle et al. 1989). By 1957, it was apparent that *Ribes* eradication was not only ineffective but also costly (Ketcham et al. 1968), and in 1966 control efforts aimed at *Ribes* eradication ceased (Hagle et al. 1989).

Between 1957 and 1966, antibiotics were used in an attempt to control white pine blister rust, but they were difficult to apply, costly, and produced varied results (Ketcham et al. 1968, Hagle et al. 1989).

In 1966 the Forest Service shifted its management strategy from one that attempted to control blister rust to one that essentially excluded western white pine as a featured species in timber management (Ketcham et al. 1968, Hagle et al. 1989). Four decisions, which resulted from the inability of previous measures to control white pine blister rust and protect western white pine, signaled this shift (Ketcham et al. 1968, Hagle et al. 1989):

1. Species other than white pine were to be favored in weeding and thinning operations
2. Western white pine would no longer be planted on an operational basis
3. Species mixtures best adapted to the site, exclusive of white pine, were to be created and regenerated
4. Salvage harvesting of western white pine damaged by white pine blister rust and bark beetles would be accelerated.

Planting western white pine

The shift in management from western white pine toward other species was accompanied by research to develop western white pine planting stock that was resistant to white pine blister rust. Planting second generation (F_2—filial generation two) stock as part of a larger silvicultural program is currently seen as the best, if not only, way to restore western white pine ecosystems (Fins et al. 2002); however, the variability of resistance and the inability to control blister rust through other measures warrant some special considerations when planting western white pine. Site preparation prior to planting, planting on suitable sites, monitoring stands for blister rust infection after planting, and the use of other cultural practices such as pruning can positively impact the performance of planted stock (Mahoney 2000, Fins et al. 2002, Schwandt and Ferguson 2002).

Although western white pine responds well to site preparation techniques such as mechanical scarification and prescribed fire, particularly in situations where the objective is to naturally regenerate the stand, *Ribes* also responds well to the same techniques. Consequently, minimal site preparation—such as simply clearing the planting spot of brush and debris—is recommended for planting western white pine (Mahoney 2000).

The number of trees to plant varies depending on the level of white pine desired in the stand at maturity. Bingham (1983) suggested a target of 200 trees per acre, or a 15 by 15 foot spacing, after accounting for losses to blister rust. Graham (1988) stated that a 10 by 10 foot spacing (435 trees per acre) was optimal for western white pine with regards to growth and volume production, but also notes that narrower spacing may be applicable on some sites. Planting higher densities of white pine than expected at maturity can compensate for losses to blister rust expected at the time of planting (Fins et al. 2002, Schwandt and Ferguson 2002). Planting pure white pine stands is not recommended because the variation in infection levels in F_2 stock could result in the loss of most white pine. Instead, white pine should be planted with other conifers that are suitable for the site (Schwandt and Ferguson 2002).

Ecological Restoration

Though the concept of ecological restoration is not new, its application in forest ecosystems is rapidly developing. In the western U.S., restoration tends to be associated with reducing high stand densities and altered structures as a result of decades of fire suppression, and examples of restoration treatments can be found in virtually every forest type throughout the West (Arno and Fiedler 2005). The goal of most restoration treatments is to create conditions that mimic those created by historical disturbance regimes in order to facilitate the return or manageability of natural processes (Arno and Fiedler 2005). Restoration treatments can be accomplished using silvicultural cutting treatments or prescribed burning (Arno and Fiedler 2005). Timber produced as a by-product of restoration treatments can also serve as an important resource for the forest products industry (Fiedler et al. 2001), and the value of that timber may be enough to underwrite the costs of implementing the treatment (Fiedler et al. 1999).

METHODS

Study Area

The Middle-Black area (Figure 1) encompasses over 156,000 acres in Clearwater County, Idaho. Steep and rugged mountainous terrain is found throughout the area. Seasonal access to the area is provided from the west via Forest Road 247 north of Pierce, Idaho; Forest Road 250 provides access from the east south of Superior, Montana, and from the south near Pierce, Idaho. Much of the area is roadless, and portions of seven designated roadless areas—Bighorn-Weitas, Hoodoo, Mallard-Larkins, Meadow Creek-Upper North Fork, Moose Mountain, Pot Mountain, and Siwash—are included in the study area. The North Fork of the Clearwater River, Pot Mountain, and Black Canyon are the major natural features in the area.

The predominant landtype associations (LTAs) (Ford et al. 1998) in the Middle-Black area are stream breaklands (45% of the area), alpine glaciated ridges and headlands (12%), colluvial midslopes (16%), frost-churned ridges (12%), and low-relief, rolling hills (15%) (CNF 2001). Three of these LTAs, stream breaklands, colluvial midslopes, and low-relief, rolling hills are found in low to mid-elevations, while alpine glaciated ridges and frost-churned ridges occur in high elevation areas. Grand fir (ABGR) and western redcedar (THPL) habitat types characterize the low and mid-elevation LTAs, while subalpine fir (ABLA) and mountain hemlock (TSME) habitat types are found in the high elevation LTAs. Forests of grand fir and Douglas-fir are most common in the low and mid-elevation areas, although areas dominated by western redcedar are also

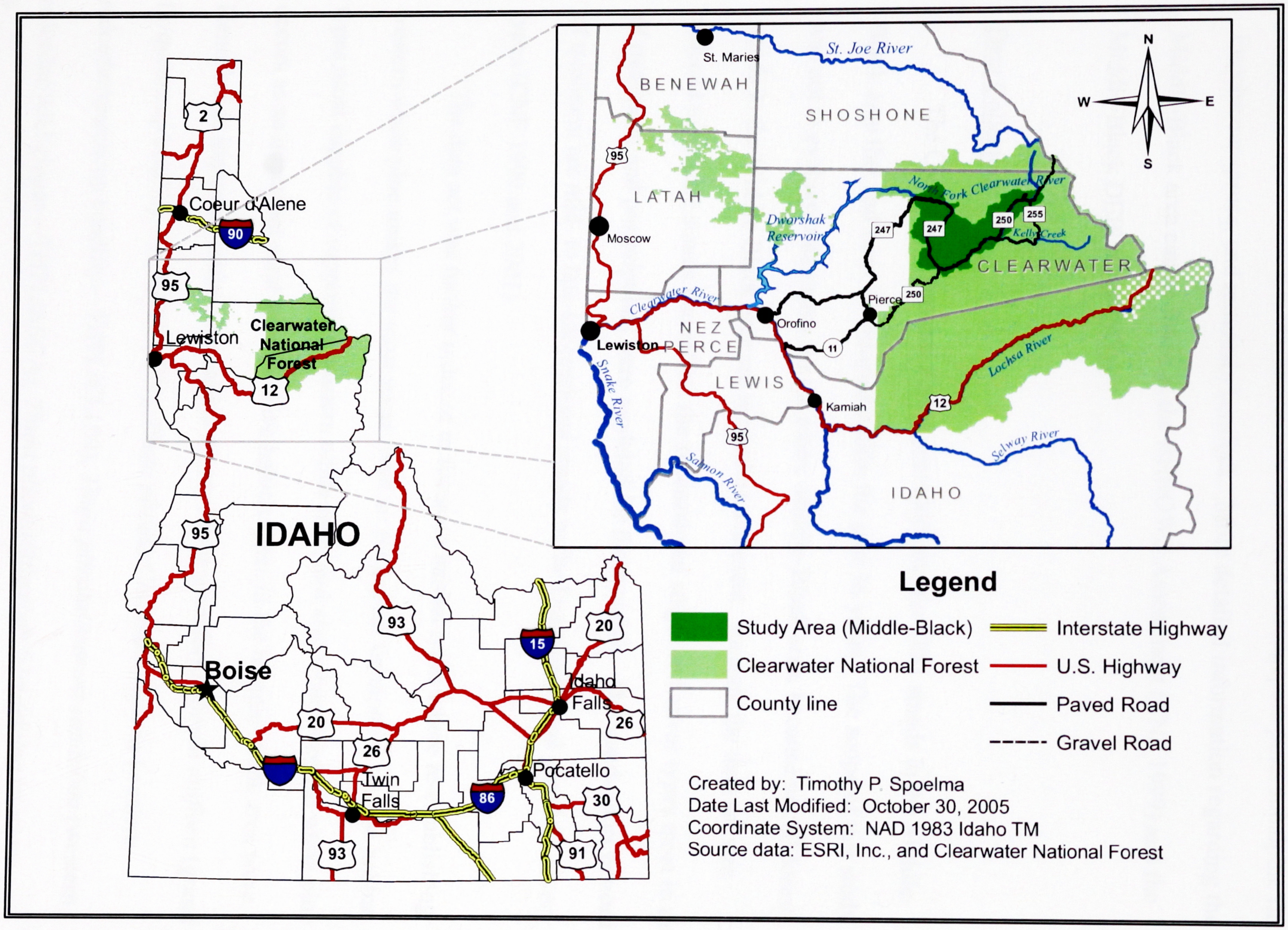

Figure 1: Location of the study area.

present. High elevation areas are typified by forests of lodgepole pine, subalpine fir, Engelmann spruce, and mountain hemlock. More detailed information regarding the Middle-Black area can be found in the BHROWS Assessment (CNF 1999) and the Middle-Black DEIS (CNF 2001).

Data Collection

The Clearwater National Forest provided data for 1881 stands in the Middle-Black area that had been inventoried within the past 36 years. The scope of this study was not to evaluate treatments for the entire Middle-Black area, because not all forest stands in the Middle-Black area are in need of treatment. Instead, the data set was reduced to include stands that reflect the successional stages and cover types most in need of treatment, and prescriptions were modeled for those stands. The stands most in need of treatment are mid- to late-successional stands in the Douglas-fir and grand fir cover types (CNF 1999 and 2001).

The data set was further reduced to focus on habitat types where re-establishing western white pine makes the most sense from an ecological standpoint, i.e., the habitat types most capable of supporting western white pine, and also where western white pine occurs as an important seral species. Five habitat types in the Middle-Black area were identified as important white pine habitat types: *Abies grandis/Clintonia uniflora* (grand fir/queencup beadlily—ABGR/CLUN), *Thuja plicata/Clintonia uniflora* (western redcedar/queencup beadlily—THPL/CLUN), *Thuja plicata/Asarum caudatum* (western redcedar/wild ginger—THPL/ASCA), *Thuja plicata/Athyrium felix-femina* (western redcedar/lady fern—THPL/ATFI), and *Thuja plicata/Adiantum pedatum* (western redcedar/maidenhair fern—THPL/ADPE) (Cooper et al. 1991). There are other habitat types in northern Idaho that are capable of supporting western white pine; however, these five habitat types are among the best suited for western white pine, and they also comprise the majority of the Middle-Black area.

The data set was further reduced by eliminating stands with less than 200 ft.^{2} of basal area per acre at the time of their inventory. Commercial thinning treatments in mid- to late-successional stands on the Clearwater National Forest typically leave from 150 to 170 ft.^{2} of basal area per acre (Dwyer 2002); therefore, 200 ft.^{2} per acre was selected as the "threshold" level for treatment. This does not imply that stands carrying less than 200 ft.^{2} could not be treated. However, such stands are lower priority for restoration, and treatments in such stands are less likely to be profitable than in stands carrying more basal area.

Silvicultural Prescriptions

The preferred alternative described in the Middle-Black DEIS (CNF 2001) calls for at least 50 percent live canopy retention following treatment. Assuming that "live canopy" corresponds to "visible sky," this level of canopy retention roughly corresponds to the 50 percent visible sky level (50% canopy cover) that offers western white pine a competitive advantage over other species (Jain et al. 2004). While this cover level exceeds occupancy standards for western white pine (>23% visible sky) (Jain et al. 2004), it does not ensure that western white pine would be the principal species occupying the site, especially if other species are able to establish prior to white pine. Establishing a canopy opening that would provide a free-to-grow condition for western white pine would increase the chances for establishing western white pine as the principal species on the site. Jain et al. (2004) identify the free-to-grow level at 92 percent visible sky or greater. Comparing the performance of treatments that left 50 percent visible sky (or 50 percent canopy cover) versus 92 percent visible sky (8 percent canopy cover) would give managers an indication of potential success of establishing western white pine in the Middle-Black area. However, applying a prescription specifying thinning to a certain percent of visible sky would be challenging because it is difficult to estimate the percent of visible sky that would be left following treatment. Traditional density measures, such as basal area, stand density index (SDI), or trees per acre can be used as a surrogate for estimating visible sky. Jain et al. (2004) state that visible sky tends to correlate poorly with traditional density measures; however, their research indicates that 50 percent visible sky is approximated by a basal area of 75 $ft.^2$ per acre, and 92 percent visible sky is approximated by 35 $ft.^2$ per acre.

Based on this information, two prescriptions were developed to re-establish western white pine (Table 1). The first reduces the overstory to 75 $ft.^2$ per acre, and the second to 35 $ft.^2$ per acre. Species preference for retention in the stand (from most desirable to least desirable) was: disease-free western white pine, western larch, ponderosa pine, lodgepole pine, Engelmann spruce, other species, Douglas-fir, subalpine fir, grand fir, western redcedar, and diseased western white pine. Trees were marked for leave beginning with the largest size class and moving toward the smallest size class for each species until the basal area target was met. Although increasing the abundance of western white pine in the post-treatment stand is a primary objective of the treatments, the western white pines still present in the Middle-Black area are generally an undesirable seed source for natural regeneration for the following reasons:

- an examination of the individual tree data for western white pine in the data set provided by the Clearwater National Forest revealed that many of the trees were infected by white pine blister rust or otherwise damaged or unsuitable to be left as a seed-bearing tree
- utilizing a natural seed source that is not naturally resistant to white pine blister rust could compromise the genetic resistance of planted rust-resistant stock
- leaving infected western white pine on the site would leave a source of blister rust spores and increase the risk of infection for both naturally and artificially regenerated white pines

When western white pine show no infection from blister rust, are naturally resistant to blister rust, or have no other damage or unsuitable characteristics (such as poor form), they would make an excellent seed source for natural regeneration and would broaden the genetic base of the future stand when combined with rust-resistant planting stock (Fins et al. 2001, Hoff et al. 1976). However, for the reasons stated previously, western white pine will not be relied on as a seed source for natural regeneration in this analysis.

Table 1 Summary of prescriptions.

Component	Prescription 1	Prescription 2
Regeneration Cutting	35 $ft.^2$/ac. reserve basal area	75 $ft.^2$/ac. reserve basal area
Site preparation	Hand pile and burn slash	Hand pile and burn slash
Reforestation	Plant 200 F_2 western white pine and 200 western larch	Plant 200 F_2 western white pine and 200 western larch

After developing the silvicultural cutting prescription, the data set was further reduced to include only stands with at least one-half (17.5 $ft.^2$) of the minimum basal area left in the prescription with the lower reserve basal area (35 $ft.^2$) comprised of either western larch and/or ponderosa pine. Stands not meeting this requirement were eliminated from consideration for treatment. Western larch and ponderosa pine could provide a desirable, although limited, seed source for regeneration following treatment. Natural regeneration of seral species is desirable, and would be necessary to augment regeneration from artificial sources to achieve desired stocking levels of seral species in the post-treatment stand. This winnowing procedure left a subset of 28 stands to be used for simulating treatments (Table 2).

Site preparation activities following overstory treatment are necessary to dispose of slash from harvesting operations and prepare the seedbed for natural regeneration of seral species. The same site preparation method—hand piling and burning slash—is prescribed following both silvicultural cutting prescriptions. This method will dispose of logging slash and minimize *Ribes* regeneration following the timber harvest. Given that artificial regeneration is the primary means for regenerating the stands following treatment, the fact that hand piling and burning will not prepare a receptive seedbed over broad areas is not a major issue. Mechanical site preparation (scarification) was not prescribed because its use is precluded in most of the Middle-Black area due to the steep terrain, which limits operability. Although broadcast burning may dispose of slash more effectively than hand means and may prepare a better seedbed for natural regeneration, risks of escape, potential loss of reserve trees, and the possibility of soil damage make it a questionable alternative, especially on the steep slopes in the Middle-Black area.

Table 2: Characteristics of stands used for simulating treatments.

Stand ID	Successional Stage	Slope (percent)	Elevation (100's feet)	Aspect (degrees)	Habitat Type	Cover Type	Acres
33109009	late-seral	0	48	135	ABGR/CLUN	DF	14
34508053	late-seral	40	48	225	ABGR/CLUN	GF	37
34509084	late-seral	40	44	180	ABGR/CLUN	GF	42
34509091	late-seral	25	48	270	ABGR/CLUN	GF	44
34702009	late-seral	0	48	90	ABGR/CLUN	GF	28
34508051	mid-seral	15	46	270	ABGR/CLUN	GF	4
34509002	mid-seral	0	48	180	ABGR/CLUN	GF	19
30401006	late-seral	58	42	315	THPL/ASCA	DF	55
31206010	late-seral	60	39	270	THPL/ASCA	DF	21
32103040	late-seral	42	47	270	THPL/ASCA	GF	46
32003013	mid-seral	45	44	360	THPL/ASCA	DF	38
32202008	mid-seral	61	34	315	THPL/ASCA	GF	64
34508052	late-seral	60	47	270	THPL/ATFI	DF	6
31201051	late-seral	45	39	45	THPL/CLUN	DF	36
31206013	late-seral	53	39	225	THPL/CLUN	DF	13
31501057	late-seral	62	48	45	THPL/CLUN	DF	18
31503044	late-seral	65	24	135	THPL/CLUN	GF	9
34509081	late-seral	30	44	180	THPL/CLUN	GF	40
11608016	mid-seral	40	42	180	THPL/CLUN	DF	34
31501033	mid-seral	72	30	45	THPL/CLUN	DF	30
31501066	mid-seral	56	35	90	THPL/CLUN	DF	12
31503007	mid-seral	63	48	45	THPL/CLUN	DF	10
31505013	mid-seral	50	34	360	THPL/CLUN	GF	33
31603022	mid-seral	42	44	270	THPL/CLUN	GF	36
31603066	mid-seral	57	24	315	THPL/CLUN	GF	82
31903034	mid-seral	41	47	225	THPL/CLUN	GF	57
32101046	mid-seral	35	23	270	THPL/CLUN	GF	16
32202009	mid-seral	74	30	225	THPL/CLUN	GF	29

Because the existing seed source of seral species is limited and most likely insufficient to gain desired levels of stocking, planting rust-resistant (F_2) western white pine and western larch seedlings would follow site preparation activities. This would ensure that the desired species are on-site following regeneration cutting and site preparation. Both prescriptions call for planting 200 trees per acre of F_2 western white pine and 200 trees per acre of western larch.

Vegetation Analysis

Because of the limited time and resources available for this study, treatments were simulated using forest modeling software, rather than implemented in the field. The Forest Vegetation Simulator (FVS) developed by the United States Forest Service is capable of modeling silvicultural treatments to a stand and projecting stand growth following the treatment (Stage 1973; Wycoff et al. 1982). FVS uses variants to model growth and yield based on the geographical area of interest. The Inland Empire variant (also known as the North Idaho variant) of FVS, developed from Stage's original Prognosis model (1973), was used to model growth and yield for the stands in this study.

One limitation of FVS is its inability to "choose" which trees are left in the stand during a treatment as a marking crew could. Hence, treatments modeled using FVS tend to focus on what is cut from a stand, rather than what is left. Researchers at the University of Montana have developed algorithms capable of selecting which trees will be left in a stand during treatment (Fiedler and Robertson 2002), and these protocols were used to simulate the cutting treatments specified for each prescription. The marking algorithms operate outside the framework of FVS; therefore, it was necessary to "grow" each of the 28 stands selected for simulation to a common starting year, since the inventory year is not consistent for each stand. Each stand was projected from its inventory date to the year 2002. Stand tables were developed to reflect 2002 conditions, and the stand tables were then converted to a format suitable as input for the harvesting algorithm. After the harvesting portion of the treatments were simulated, the data were re-formatted for use with FVS. Planting activities were then simulated before projecting each stand forward at 5-year intervals, for a total of 20 years.

The Regeneration Establishment Model (Ferguson and Crookston 1991), which operates as a part of FVS, was used to simulate planting and natural regeneration. The COVER extension (Moeur 1985) for FVS was used to track changes in canopy cover for each cycle. The FVS_Stand post-processor (Vandendriesche 2002) was used to generate stand tables for each simulation.

Harvesting Costs/Revenues Analysis

The volume of timber removed during each treatment was calculated in both cubic feet and board feet for each species using FVS.

Three-year average log market prices (2002-2004) were used to determine the value of the timber removed under each treatment. The log market prices used for this analysis were provided by Vincent P. Corrao of Northwest Management, Inc., in Moscow, Idaho.

Harvesting costs for skyline systems were estimated using the skyline yarding cost equation from Keegan et al. (2002). This equation uses the average diameter at breast height (d.b.h.) in inches of timber removed, the volume per acre removed in green tons, and the average yarding distance in feet to provide a stump-to-loaded truck cost—which includes planning, felling, yarding, and loading—per green ton. Because removal volumes were calculated in thousand board feet (MBF), a conversion factor of 7.0 green tons/MBF was used to convert removal volumes to green tons.

Two scenarios were developed to analyze log hauling costs. The first assumes a 100 mile one-way distance to a receiving mill, and the second a 200-mile distance. Log hauling was assumed to cost $550 per 8-hour day (or $68.75 per hour). Using the Forest Residues Trucking Simulator (FoRTS v. 5) (Rummer 2005), average speed by road type and hauling times were calculated for each distance. Per trip hauling costs were derived using the average hauling time and hourly cost. A conversion factor of 4.5 MBF/truckload was used to calculate the hauling cost/MBF.

Activity fuels (slash) treatment costs were calculated using fixed values from Fiedler et al. (2004). These values range from $0 to $280 per acre for piling and burning material in 4-inch d.b.h. or smaller size classes, depending on the number of stems in those size classes removed per acre. For non-merchantable material in the 6-inch d.b.h. size class, a $5 cost per acre was added for burning this material at the landing.

Planting costs were calculated using a materials cost of $0.36 per seedling for F_2 western white pine and $0.294 per seedling for western larch (Justin 2005), and a labor cost of $0.24 per seedling (Hayes 2005).

The value of the timber removed was compared with the costs of harvesting, hauling, activity fuels treatment, and planting to determine the net (plus or minus) returns of each alternative.

RESULTS

Pre-treatment Stand Conditions

Results of the data reduction and analysis of the Middle-Black stand inventory data yielded 28 stands classified within four habitat types: ABGR/CLUN (7 stands), THPL/ASCA (5 stands), THPL/ATFI (1 stand), and THPL/CLUN (15 stands). For this analysis, the single THPL/ATFI stand was included with the THPL/ASCA group, because of its proximity on the moisture gradient.

Table 3 summarizes the pre-treatment conditions for these stands. Stands averaged 1325 trees per acre and 225 $ft.^2$ basal area per acre, with a canopy cover of nearly 73 percent. Stands in the ABGR/CLUN habitat type averaged the most trees per acre but the least basal area per acre when compared to other habitat types, resulting in the lowest quadratic mean diameter of all habitat types. Canopy cover was similar among the three habitat types (Table 3).

Table 3: Summary of average pre-treatment stand conditions, 2002.

Habitat Type	No. of Stands	Trees/Acre	Basal Area/ Acre ($ft.^2$)	Quadratic Mean Diameter (in.)	Canopy Cover (percent)
ABGR/CLUN	7	1816	208	6.1	72
THPL/ASCA	6	1031	225	8.6	73
THPL/CLUN	15	1213	234	8.7	73
All Stands	28	1325	225	8.0	73

Figure 2 shows trees per acre by species and diameter class prior to treatment (all stands combined). Figure 3 shows the average diameter distribution in terms of basal area per acre by species for all stands. The greatest proportion of basal area is found in the 10- to 16-inch size classes, with grand fir, Douglas-fir, western larch, and western redcedar accounting for most of the basal area.

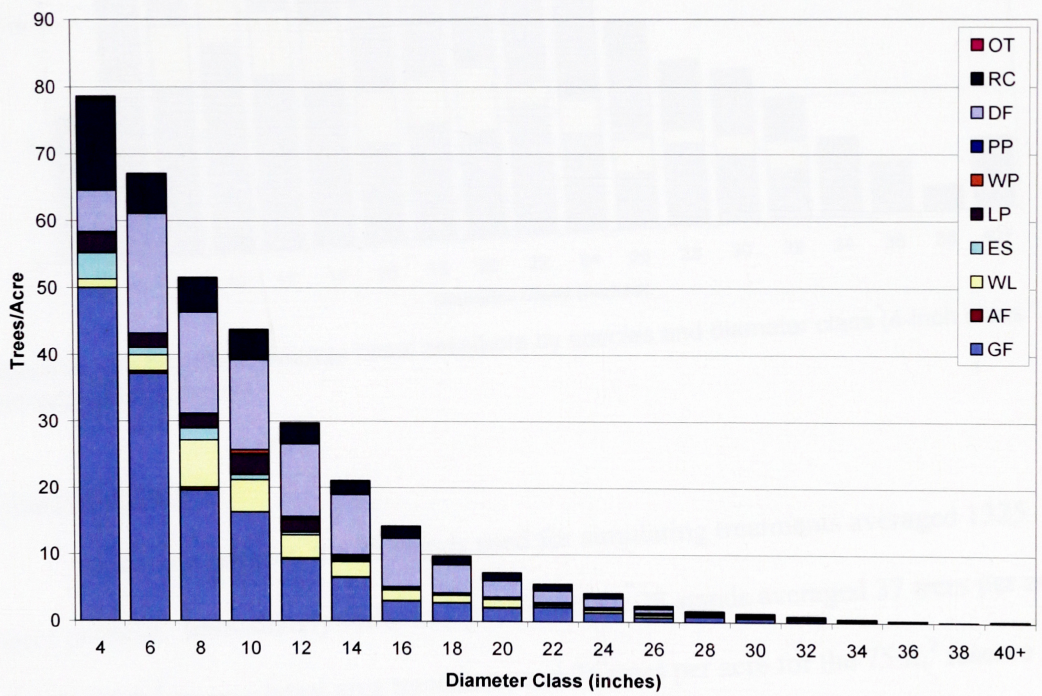

Figure 2: Pre-treatment average trees/acre by species and diameter class (4-inch class and larger) for all stands.

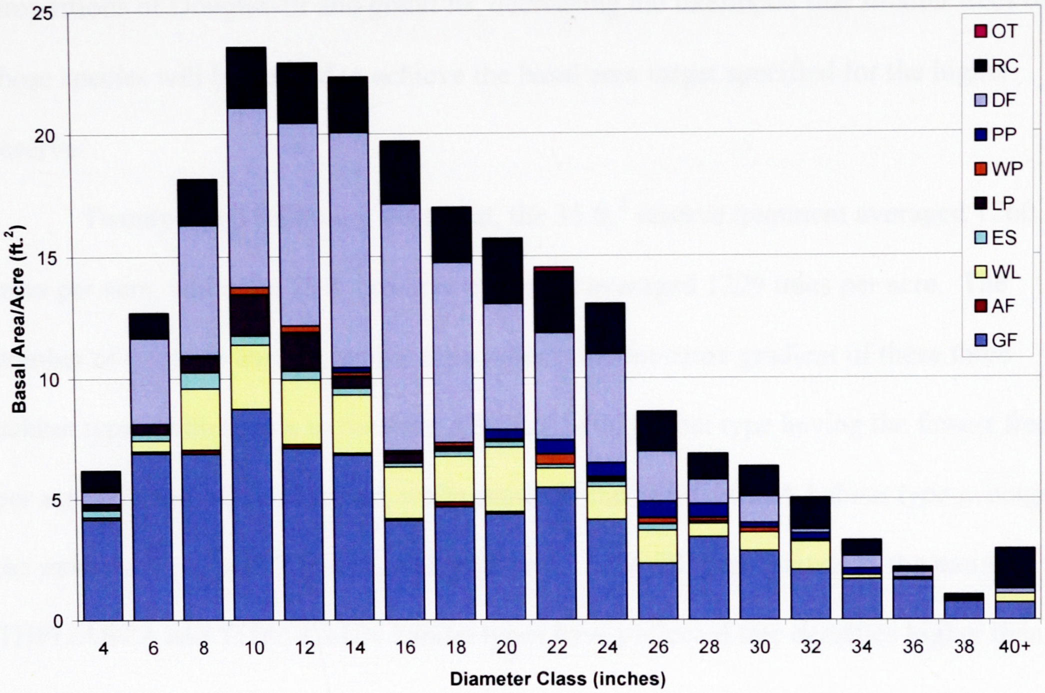

Figure 3: Pre-treatment average basal area/acre by species and diameter class (4-inch class and larger) for all stands.

Changes in Density

Prior to treatment, the 28 stands used for simulating treatments averaged 1325 trees per acre. Immediately following treatment, the 28 stands averaged 37 trees per acre for the 35 ft.^{2} reserve basal area treatment, and 76 trees per acre for the 75 ft.^{2} reserve basal area treatment (Table 4). The quadratic mean diameter of trees left under the 35 ft.^{2} reserve was 13.2 inches versus 13.5 inches for the 75 ft.^{2} reserve. This counterintuitive result can be explained by the method used to mark the leave trees in the stands where the largest trees are the first trees kept for each species. Reaching the higher reserve basal area specified for 75 ft.^{2} prescription requires keeping a higher proportion of shade-tolerant species, particularly Douglas-fir and in some cases grand fir. As shown in Figure

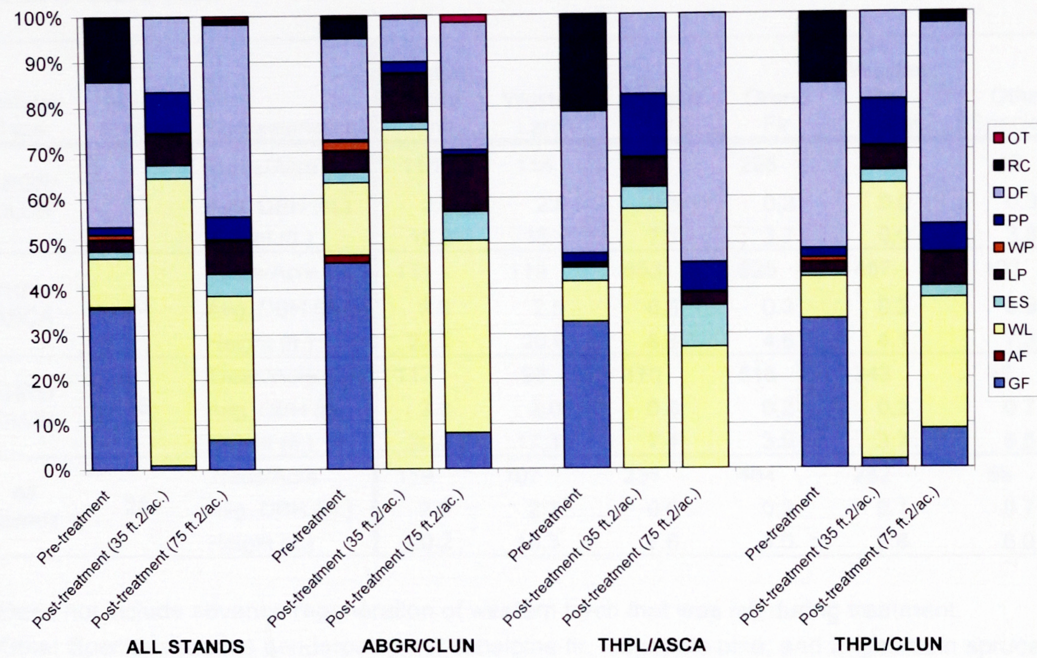

Figure 8: Percent of basal area/acre by species for pre- and initial post-treatment conditions.

<u>Regeneration</u>

Assessing regeneration following treatment is a critical component in determining treatment effectiveness, as well as for gaining an indication of cultural activities that may be needed to control species composition and density as the stand develops. The objective of both treatments was to increase presence of western white pine and western larch in the post-treatment stand and to create conditions that favor their development into a future seed source.

Tables 6 and 7 show regeneration for each prescription 20 years after treatment. The density of western white pine and western larch, the two species planted following treatment, is not greater than that of the other species, but their height and diameter is, following treatment compared to the 35 ft.^{2} prescription, while stands in the THPL/CLUN habitat type had slightly less than twice as many trees per acre for the 75 ft.^{2} prescription compared to the 35 ft.^{2} prescription. However, the number of trees per acre for both prescriptions 20 years after treatment is nearly equal for all habitat types, indicating that the higher reserve basal area (and trees per acre) of the 75 ft.^{2} prescription is not adversely impacting natural regeneration in these stands in terms of tree density.

Table 5 shows the change in basal area per acre from pre-treatment levels to 20 years post-treatment, and reveals an interesting response to treatment at the habitat type level. Increases in basal area for the first 20 years following treatment were nearly uniform (approximately 25 ft.^{2} per acre) for each habitat type for both prescriptions; however, the change in trees per acre (Table 4) was markedly different among habitat types. This indicates that for the first 20 years following treatment, most of the basal area growth in these stands is from the reserve trees left during treatment and not from regenerating trees.

The basal area increment for these stands is less than expected, particularly when considering that the study area falls in one of the most productive regions of the Inland Northwest, and that the sites that these stands grow on are among the most productive for forest growth in this region. A possible explanation for this lies in the way that the treatments were simulated. FVS uses diameter increment data to calibrate the growth model used for projecting stand growth, but for this analysis the harvesting portion of the treatments was done outside of the FVS framework. This resulted in the inadvertent loss of the diameter increment data used to calibrate the growth model; therefore, the model's default growth rates were used to project stand growth following treatment. An attempt was made to incorporate pre-treatment growth data into post-treatment projections, but this had little impact on the overall performance of the model, and also failed to recognize the effects of disturbance since it is a pre-treatment growth rate as opposed to a post-treatment growth rate.

Table 5: Pre-treatment, initial post treatment, and 20 years post-treatment basal area/ acre

Habitat Type	No. of Stands	Pre-treatment	Initial Post-treatment Target BA = 35	Initial Post-treatment Target BA = 75	20 years Post-treatment Target BA = 35	20 years Post-treatment Target BA = 75
ABGR/CLUN	7	208	35	75	59	98
THPL/ASCA	6	225	35	75	61	103
THPL/CLUN	15	234	35	75	63	98
All Stands	28	225	35	75	62	99

Figures 4 and 5 show the diameter distribution of trees per acre by species for each prescription. Comparing these figures to Figure 2 shows each prescription's effects on the diameter distribution as well as the species composition. Following treatment, the shape of the diameter distribution for both prescriptions is similar to the pre-treatment distribution, with the exception of the 4- and 6-inch size classes. Grand fir and Douglas-fir had the greatest number of trees prior to treatment; following treatment, western larch has the greatest number of trees for both prescriptions.

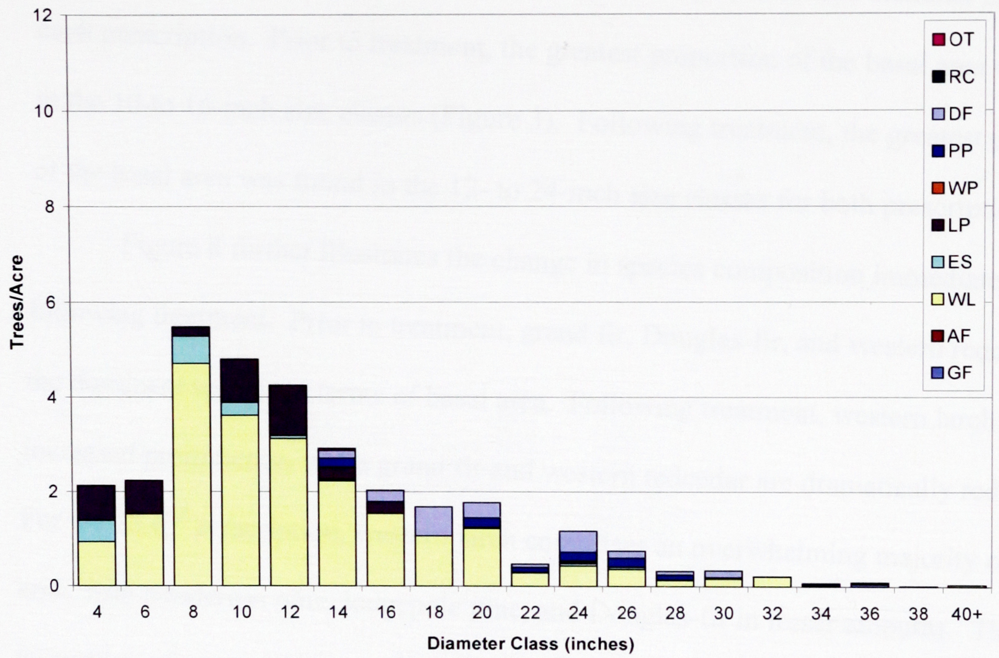

Figure 4: Initial post-treatment average trees/acre by species and diameter class (4-inch class and larger) for all stands, target basal area/acre = 35 $ft.^2$

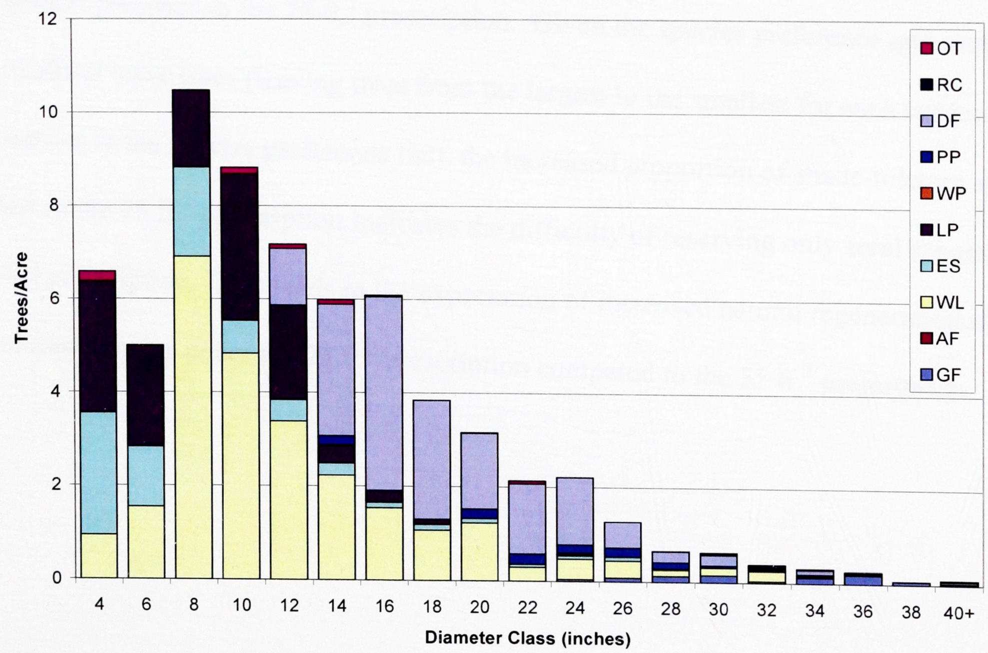

Figure 5: Initial post-treatment average trees/acre by species and diameter class (4-inch class and larger) for all stands, target basal area/acre = 75 $ft.^2$

Figures 6 and 7 show the basal area per acre by species and diameter class for each prescription. Prior to treatment, the greatest proportion of the basal area was found in the 10-to 16-inch size classes (Figure 3). Following treatment, the greatest proportion of the basal area was found in the 12- to 24-inch size classes for both prescriptions.

Figure 8 further illustrates the change in species composition immediately following treatment. Prior to treatment, grand fir, Douglas-fir, and western redcedar were the dominant species in terms of basal area. Following treatment, western larch has increased prominence, while grand fir and western redcedar are dramatically reduced. For the 35 $ft.^2$ prescription, western larch comprises an overwhelming majority of basal area, with ponderosa pine, lodgepole pine, and Douglas-fir in lesser amounts. The proportion of western larch following treatment is less for the 75 $ft.^2$ prescription compared to the 35 $ft.^2$ prescription. Douglas-fir and grand fir, however, have a much greater presence in the 75 $ft.^2$ prescription. Given the species preference and method for marking leave trees (leaving trees from the largest to the smallest for each successive species in the species preference list), the increased proportion of shade-tolerant species left in the 75 $ft.^2$ prescription indicates the difficulty of reserving only seral species using that prescription. This leads to the expectation of increased natural regeneration of shade tolerant species under the 75 $ft.^2$ prescription compared to the 35 $ft.^2$ prescription.

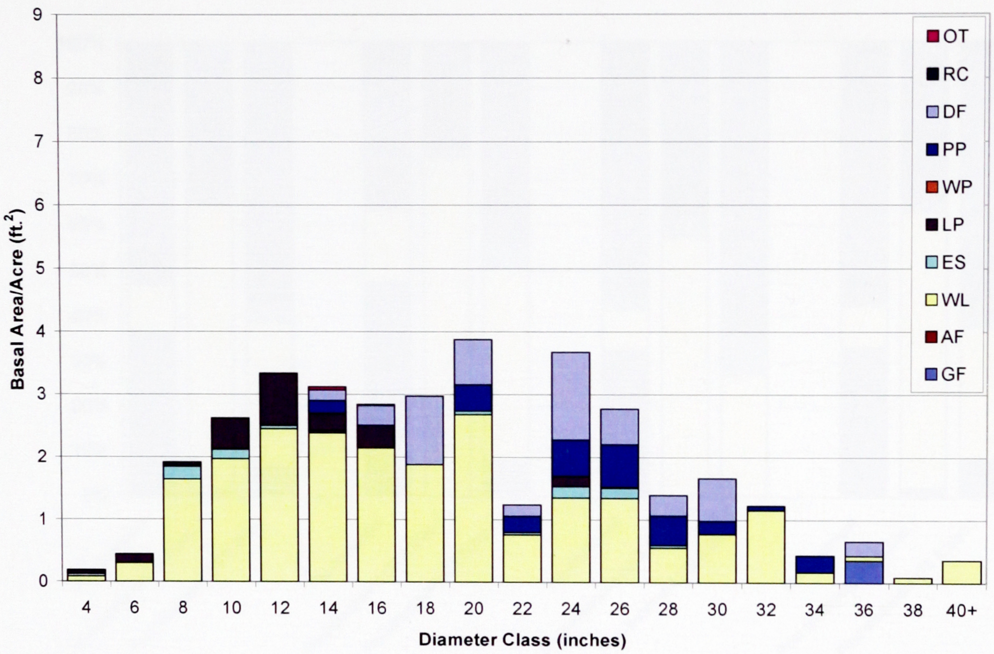

Figure 6: Initial post-treatment average basal area/acre by species and diameter class (4-inch class and larger) for all stands, target basal area/acre = 35 ft.^{2}

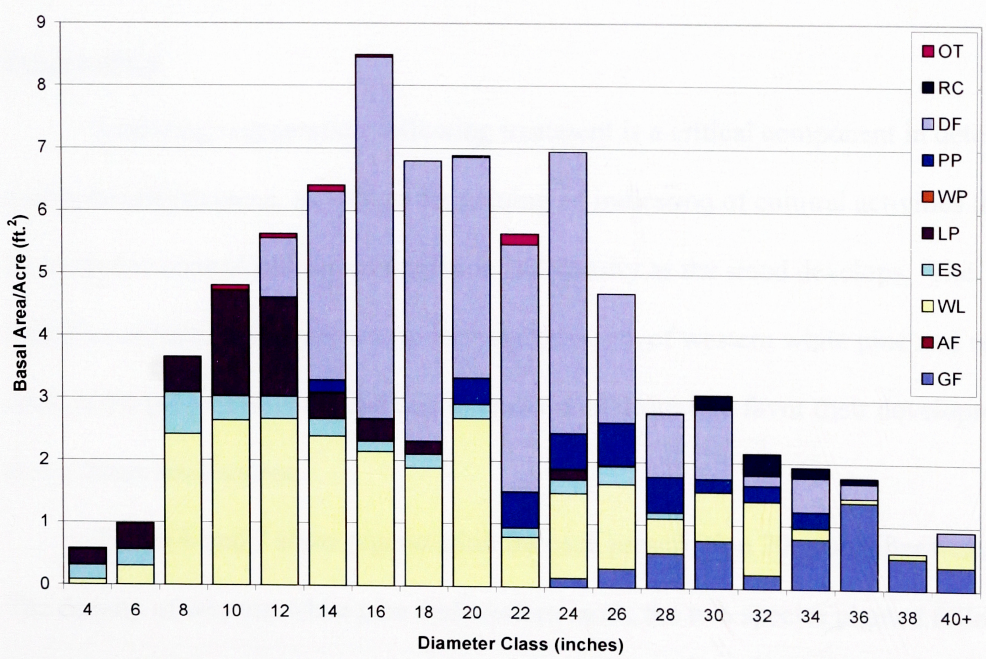

Figure 7: Initial post-treatment average basal area/acre by species and diameter class (4-inch class and larger) for all stands, target basal area/acre = 75 ft.^{2}

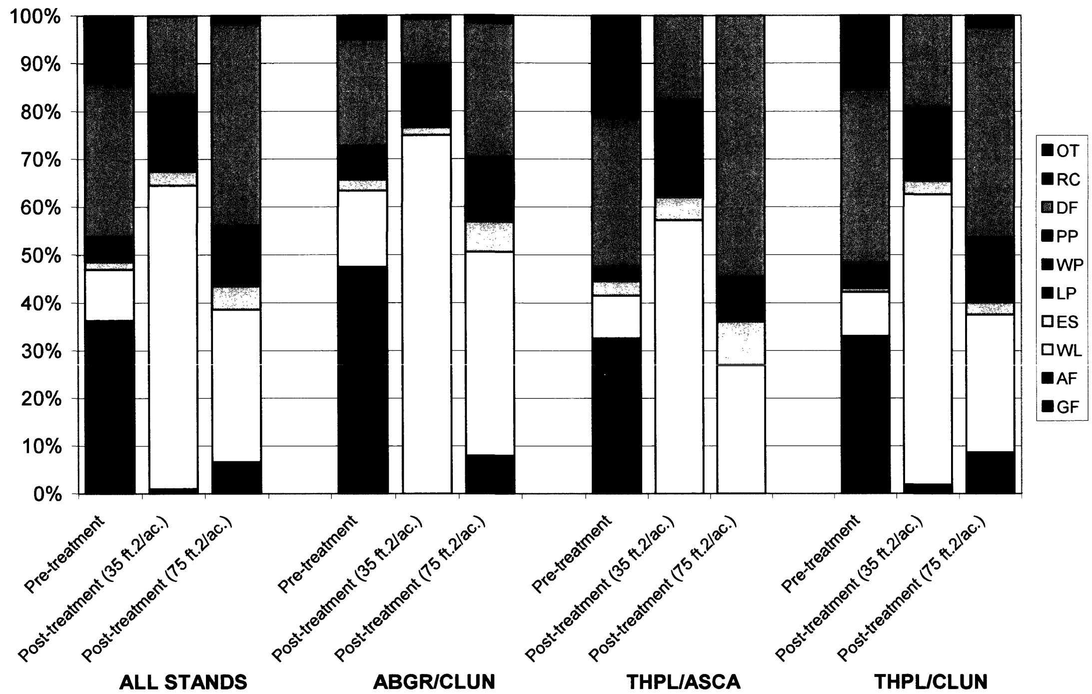

Figure 8: Percent of basal area/acre by species for pre- and initial post-treatment conditions.

<u>Regeneration</u>

Assessing regeneration following treatment is a critical component in determining treatment effectiveness, as well as for gaining an indication of cultural activities that may be needed to control species composition and density as the stand develops. The objective of both treatments was to increase presence of western white pine and western larch in the post-treatment stand and to create conditions that favor their development into a future seed source.

Tables 6 and 7 show regeneration for each prescription 20 years after treatment. The density of western white pine and western larch, the two species planted following treatment, is not greater than that of the other species, but their height and diameter is,

Table 6: Regeneration characteristics by species and habitat type 20 years post-treatment for the 35 ft.^{2} prescription [a]

Habitat Type	No. of Stands	Characteristics	Western White Pine	Western Larch	Douglas -fir	Grand Fir	Western Red-cedar	Other Species [b]
ABGR/ CLUN	7	Trees/Acre	115	115	111	295	0	42
		Avg. DBH (in.)	2.6	2.8	0.5	0.2	0.0	0.3
		Height (ft.)	18.2	18.1	7.1	3.7	0.0	3.8
THPL/ ASCA	6	Trees/Acre	131	119	553	625	457	103
		Avg. DBH (in.)	3.0	2.5	0.8	0.3	0.2	0.9
		Height (ft.)	22.7	20.9	8.8	4.6	4.1	7.3
THPL/ CLUN	15	Trees/Acre	117	98	170	516	343	48
		Avg. DBH (in.)	3.2	2.0	0.6	0.2	0.2	0.7
		Height (ft.)	20.2	17.3	7.4	3.9	3.7	6.5
All Stands	28	Trees/Acre	119	107	237	484	282	58
		Avg. DBH (in.)	3.0	2.3	0.6	0.2	0.1	0.7
		Height (ft.)	20.2	18.3	7.6	4.0	2.8	6.0

[a] Does not include advance regeneration of western larch that was left during treatment.

[b] Other Species includes ponderosa pine, subalpine fir, lodgepole pine, and Engelmann spruce

Table 7: Regeneration characteristics by species and habitat type 20 years post-treatment for the 75 ft.^{2} prescription [a]

Habitat Type	No. of Stands	Characteristics	Western White Pine	Western Larch	Douglas -fir	Grand Fir	Western Red-cedar	Other Species [b]
ABGR/ CLUN	7	Trees/Acre	85	95	97	279	0	63
		Avg. DBH (in.)	1.9	2.0	0.3	0.1	0.0	0.2
		Height (ft.)	14.2	13.6	5.1	3.1	0.0	2.3
THPL/ ASCA	6	Trees/Acre	95	93	263	573	440	113
		Avg. DBH (in.)	2.2	1 7	0.4	0.2	0.2	0.4
		Height (ft.)	17.6	15.1	5.6	3.5	3.5	4.7
THPL/ CLUN	15	Trees/Acre	89	95	172	474	374	45
		Avg. DBH (in.)	2.4	1.9	0.3	0.2	0.1	0.4
		Height (ft.)	16.0	13.5	5.1	3.2	3.2	4.4
All Stands	28	Trees/Acre	89	94	173	446	295	64
		Avg. DBH (in.)	2.3	1.9	0.3	0.2	0.1	0.4
		Height (ft.)	15.9	13.9	5.2	3.2	2.4	3.9

[a] Does not include advance regeneration of western larch that was left during treatment.

[b] Other Species includes ponderosa pine, subalpine fir, lodgepole pine, and Engelmann spruce

particularly for the 35 $ft.^2$ prescription. These results provide evidence that the treatments have created conditions favorable for the planted species to not only survive, but also capture a competitive advantage over naturally regenerating species.

Grand fir has the greatest regeneration density following treatment, followed by western redcedar and Douglas-fir. The proportions of all species are nearly equal for both prescriptions (Figures 9 and 10), an unexpected result given the higher proportion of tolerant species in the overstory in the 75 $ft.^2$ prescription.

In terms of height and diameter growth, western white pine and western larch greatly outperform naturally regenerating species. Height and diameter growth are higher for the 35 $ft.^2$ prescription compared to the 75 $ft.^2$ prescription for all species, a likely result of the more favorable growth conditions provided by the 35 $ft.^2$ prescription. For both prescriptions, height and diameter growth among species show a decreasing trend as shade tolerance increases. One notable exception to this trend is shade-intolerant western larch, which was out-performed by western white pine, a slightly more shade tolerant species. This can be explained by the level of overstory remaining after treatment: western larch grows best in full sunlight, while western white pine is tolerant of a moderate degree of shade.

Western white pine under the 35 $ft.^2$ prescription averages 119 trees per acre with a diameter of 3 inches and a height of 20 feet 20 years after treatment. For the 75 $ft.^2$ prescription, it averages 89 trees per acre with a diameter of 2.3 inches and a height of 16 feet 20 years after treatment. The THPL/ASCA habitat type has the most western white pine per acre for both prescriptions, as well as the greatest average height. Diameter

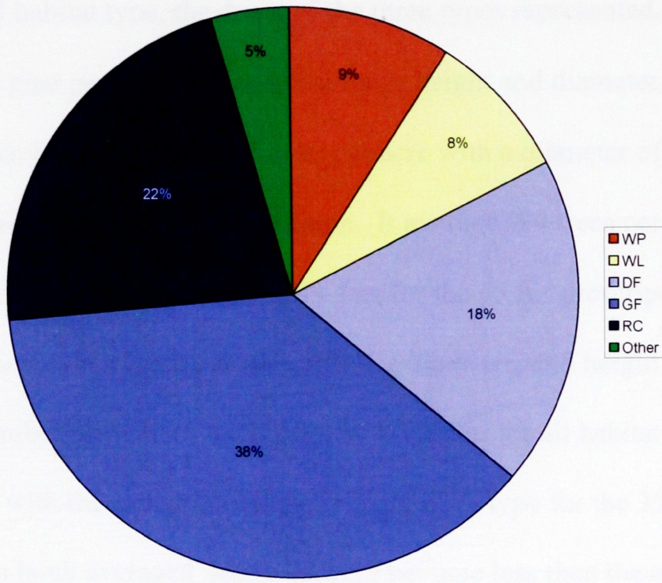

Figure 9: Percent of regenerating trees/acre by species for the 35 ft.^{2} prescription.

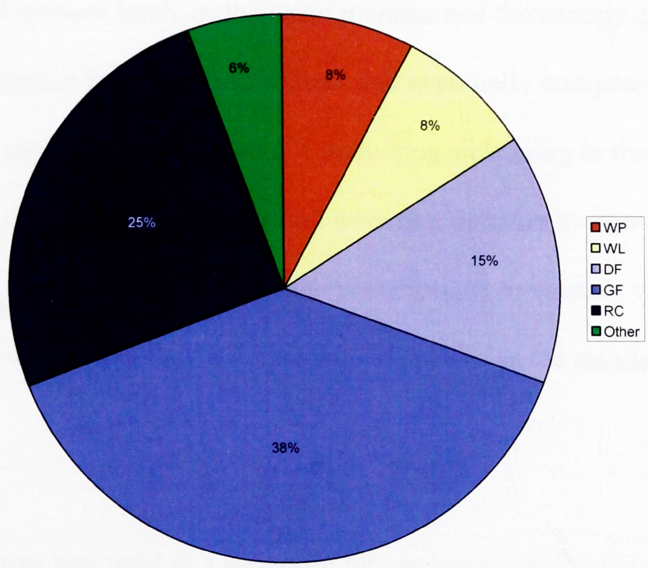

Figure 10: Percent of regenerating trees/acre by species for the 75 ft.^{2} prescription.

growth is greatest on the THPL/CLUN habitat type for both prescriptions. The ABGR/CLUN habitat type, the driest of the three types represented, has the fewest western white pine per acre and lowest average height and diameter.

Western larch averages 107 trees per acre with a diameter of 2.3 inches and a height of 18 feet for the 35 $ft.^2$ prescription. It averages 94 trees per acre with an average diameter of 1.9 inches and a height of 14 feet for the 75 $ft.^2$ prescription. There are no clear trends for western larch per acre, average diameter, and height at the habitat type level. The number of western larch per acre is similar for all habitat types for both prescriptions, with the exception of the THPL/CLUN type for the 35 $ft.^2$ prescription, where western larch averaged nearly 20 trees per acre less than the other habitat types. Average diameter is greatest for the ABGR/CLUN habitat type for both prescriptions, and height growth is greatest on the THPL/ASCA habitat type.

Although the treatments were successful in affording an advantage to western white pine and western larch, as the stand matures and the canopy closes, shade-tolerant species will increase in growth and stature, and eventually compete more effectively with western white pine and western larch. Conducting a cleaning in the stand, a silvicultural treatment that removes undesirable small trees that threaten to overtop the desirable trees, would sustain the advantage given by the prescriptions to western white pine and western larch and help ensure that they are the featured species as the stands mature.

Canopy Cover

Basal area was used as a surrogate for canopy cover in applying the prescriptions; hence, evaluating post-treatment canopy cover gives an indication of the efficacy of each treatment for producing the desired canopy cover. Furthermore, estimates of canopy cover in the years following treatment may indicate how long canopy conditions favoring western white pine will persist. Table 8 shows pre-treatment, initial post-treatment, and 20-year post-treatment estimates of canopy cover for the 35 ft.^{2} and 75 ft.^{2} prescriptions.

Pre-treatment canopy cover levels for all 28 stands used in the simulations averaged 73 percent, with a range of 54 to 97 percent. There was little variation in canopy cover among habitat types; however, mid-seral stands tended to have a greater canopy cover than late-seral stands (77 percent versus 68 percent).

Table 8: Average pre-treatment, initial post-treatment, and 20-year post-treatment canopy cover (percent).

			Target = 35 ft.^{2}		Target = 75 ft.^{2}	
Habitat Type	Successional Stage (number of stands)	Pre-treatment	Initial Post-treatment	20 years Post-treatment	Initial Post-treatment	20 years Post-treatment
ABGR/CLUN	Late-seral (5)	69	12	28	25	34
	Mid-seral (2)	78	13	36	27	40
	All (7)	72	12	30	25	36
THPL/ASCA	Late-seral (4)	70	11	46	25	46
	Mid-seral (2)	79	13	54	28	53
	All (6)	73	12	49	26	48
THPL/CLUN	Late-seral (5)	65	10	35	20	35
	Mid-seral (10)	77	14	45	26	46
	All (15)	73	13	41	24	42
All Stands	Late-seral (14)	68	11	36	23	38
	Mid-seral (14)	77	14	45	26	46
	All (28)	73	12	40	25	42

For the 35 ft.^{2} prescription, the desired canopy cover was 8 percent. The prescription achieved an average canopy cover of 12 percent (88 percent visible sky) in the 28 stands used for simulating treatments, with a range from 9 to 16 percent. There was little difference in canopy cover among habitat types, as stands in the ABGR/CLUN habitat type averaged 12 percent , THPL/CLUN averaged 13 percent, and THPL/ASCA averaged 12 percent. Mid-seral stands averaged 14 percent canopy cover immediately following treatment, while late-seral stands averaged 11 percent.

Twenty years after treatment, the 35 $ft.^2$ prescription averaged 40 percent canopy cover, well below the competitive advantage level of 50 percent canopy cover identified by Jain et al. (2004). Among habitat types there was much more variation in canopy cover at 20 years post-treatment, as stands in ABGR/CLUN averaged 30 percent, THPL/CLUN averaged 41 percent, and THPL/ASCA averaged 49 percent. Mid-seral stands averaged 45 percent canopy cover at 20 years, and late-seral stands averaged 36 percent.

For the 75 $ft.^2$ prescription, the desired canopy cover was 50 percent and the prescription achieved an average of 25 percent. As with the 35 $ft.^2$ prescription, there was little variation among habitat types immediately after treatment. Mid-seral stands averaged 26 percent canopy cover immediately following treatment, and late-seral stands averaged 23 percent.

After 20 years, the 75 $ft.^2$ reserve treatment averaged 42 percent canopy cover. There was some variation among habitat types, as ABGR/CLUN stands averaged 36 percent canopy cover, THPL/CLUN stands averaged 42 percent, and THPL/ASCA stands averaged 48 percent. Mid-seral stands averaged 46 percent canopy cover, and late-seral stands averaged 38 percent.

The results indicate that between the two treatments, the 35 $ft.^2$ reserve comes much closer to meeting its target of 8 percent canopy cover than the 75 $ft.^2$ reserve does of meeting its target of 50 percent cover. A possible explanation for the 75 $ft.^2$ prescription having a much lower canopy cover level than anticipated is that the additional trees kept to meet that target basal area for that prescription were typically Douglas-fir and grand fir—two narrow-crowned species that may contribute relatively less canopy cover than other species of similar size. The fact that the 75 $ft.^2$ reserve treatment left much less canopy cover than the 50 percent level that it was meant to achieve means that more basal area would need to be left on site to achieve 50 percent canopy cover. As previously shown, leaving a higher level of basal area comes at the cost of reduced numbers of western white pine and western larch in the post-treatment stand, as well as reduced tree vigor in terms of height and diameter growth for those species.

Over a 20-year period, both treatments have canopy cover levels that remain below the 50 percent canopy cover level where western white pine has a competitive advantage over other species. This shows that the effects of each treatment are not short-lived, and provide western white pine and western larch with at least two decades to express dominance in terms of height and diameter growth over other species regenerating naturally. The 35 $ft.^2$ prescription shows a 28 percent increase in canopy cover over a 20-year period versus a 17 percent increase for the 75 $ft.^2$ prescription. This differential is understandable given that regeneration in the 35 $ft.^2$ reserve treatment shows a better response in terms of height and diameter growth following treatment, resulting in regenerating trees with larger crowns than those in the 75 $ft.^2$ reserve treatment. Cultural treatments to manipulate species composition and density in the post-treatment stand would slightly reduce canopy cover, further enhancing the advantage that western white pine and western larch show over other species.

Treatment Costs and Revenues

Comparing the costs of performing a treatment to the value of timber harvested as a part of the treatment provides managers with critical information regarding the economic feasibility of the treatment. If the costs of the treatment outweigh the value of the timber by-products, performing the treatment will require a subsidy to cover the extra costs. While making a profit is not a primary objective of restoration treatments, profitable operations make it more likely that restoration will occur. Thus, it is important to examine a hypothetical harvesting situation for these stands and compare the costs of the prescribed treatments to the value of timber by-products harvested.

One harvesting scenario with two log hauling distances was examined. Because most of the terrain in the Middle-Black area is too steep for ground-based harvesting systems, the harvesting scenario modeled for this study utilized a skyline logging system with an assumed average yarding distance of 1800 feet. It was assumed that existing roads would be used for harvesting; therefore, road-building costs were not included in the analysis.

Tables 9 and 10 compare the average volume removed per acre, the average size of the timber removed, and the average costs of harvesting that timber for both prescriptions. The 35 ft.^{2} prescription removes about 7 MBF more per acre than the 75 ft.^{2} prescription, and the average d.b.h. of the removed trees is also greater for the 35 ft.^{2} prescription. This is consistent with the implementation of the prescriptions, where the largest trees were the first kept (and the smallest the first removed) for each species until the basal area target was met. Because of this, a larger number of larger trees were removed to meet the lower reserve basal area of the 35 ft.^{2} prescription compared to the 75 ft.^{2} prescription.

Although more timber was removed under the 35 ft.^{2} prescription, the costs of removal per MBF are less than the 75 ft.^{2} prescription. This is not unexpected, as harvesting costs typically decrease as average diameter and volume removed increase. However, due to the greater volume removed per acre for the 35 ft.^{2} prescription, per acre yarding costs are higher for the 35 ft.^{2} prescription than the 75 ft.^{2} prescription. These costs reflect all activities involved from the stump-to-loaded truck.

Table 9: Average skyline yarding costs for the 35 ft.^{2} reserve basal area prescription.

Habitat Type	No. of Stands	Merchantable Volume removed/acre (MBF, Scribner) [a]	Quadratic Mean Diameter of removals	Yarding cost/acre	Yarding cost/MBF
ABGR/CLUN	7	25.5	12.5	$6,172	$249
THPL/ASCA	6	27.6	13.9	$6,187	$232
THPL/CLUN	15	31.0	13.2	$7,032	$241
All Stands	28	28.9	13.2	$6,636	$241

[a] Merchantable volume removed per acre does not include timber in the 6-inch size class, while yarding costs include the cost of removing timber in the 6-inch size class.

Table 10: Average skyline yarding costs for the 75 ft.^{2} reserve basal area prescription.

Habitat Type	No. of Stands	Merchantable Volume removed/acre (MBF, Scribner) [a]	Quadratic Mean Diameter of removals	Yarding cost/acre	Yarding cost/MBF
ABGR/CLUN	7	18.4	12.0	$4,646	$259
THPL/ASCA	6	21.2	13.4	$4,900	$240
THPL/CLUN	15	22.8	12.5	$5,431	$256
All Stands	28	21.4	12.5	$5,121	$254

[a] Merchantable volume removed per acre does not include timber in the 6-inch size class, while yarding costs include the cost of removing timber in the 6-inch size class.

Two log-hauling scenarios were examined, the first involving a 100-mile one-way haul, and the second a 200-mile haul. Log hauling costs reflect an average speed that was calculated based on the distance traveled by road type. For the 100-mile one-way haul, 4 miles were assumed to be on forest roads, 28 miles on gravel roads, 30 miles on paved roads, and 38 miles on 2-lane highways. For the 200-mile haul, distances were the same as the 100-mile haul for the first 100 miles, and the second 100 miles was assumed to be on 2-lane highways. These distances and road types resulted in a 31 mph average speed for the 100-mile haul, and a 41 mph speed for the 200-mile haul. Costs per MBF were $98 for the 100-mile haul and $150 for the 200-mile haul. Multiplying the costs per MBF by the volume removed per acre gives the per acre log-hauling costs for each distance and prescription (Table 11). Because more volume is removed under the 35 $ft.^2$ prescription, log hauling costs are higher for that prescription.

Table 11: Average log hauling costs per acre for 100-mile and 200-mile distances.

	35 $ft.^2$ prescription		75 $ft.^2$ prescription	
Habitat Type	100-mile	200-mile	100-mile	200-mile
ABGR/CLUN	$2,498	$3,823	$1,799	$2,754
THPL/ASCA	$2,706	$4,141	$2,080	$3,184
THPL/CLUN	$3,042	$4,656	$2,239	$3,426
All Stands	$2,834	$4,338	$2,095	$3,206

The estimated costs of treating activity fuels were the same for both prescriptions. These costs averaged $194 per acre, with a range from $5 to $285. Estimated planting costs were also the same for both prescriptions, at $227 per acre.

Tables 12 and 13 compare the total costs of implementing the prescriptions to the value of the timber removed. Although the total costs of implementing the treatment are higher for the 35 ft.^{2} prescription, the timber values are also higher, resulting in greater net returns per acre for the 100-mile haul and smaller losses per acre for the 200-mile haul. For both prescriptions, the average net returns per acre for the 100-mile haul were positive, while the 200-mile haul resulted in negative net returns. Net returns were negative for the ABGR/CLUN habitat type for both prescriptions and hauling distances. This is due to the fact that the ABGR/CLUN habitat type has the least volume removed per acre and the smallest average diameter of timber removed, both of which result in higher harvesting costs. Conversely, estimated net returns for THPL/ASCA stands were positive for both prescriptions and hauling distances. THPL/ASCA stands had the highest average diameter of timber removed, resulting in lower harvesting costs.

Table 12: Average net returns per acre for the 35 ft.^{2} reserve basal area prescription.

		Total Costs/acre		Net Returns/acre	
Habitat Type	Timber value/acre	100-mile haul	200-mile haul	100-mile haul	200-mile haul
ABGR/CLUN	$8,935	$9,133	$10,459	-$199	-$1,524
THPL/ASCA	$11,637	$9,320	$10,756	$2,317	$882
THPL/CLUN	$11,980	$10,472	$12,086	$1,508	-$106
All Stands	$11,145	$9,890	$11,394	$1,255	-$249

Table 13: Average net returns per acre for the 75 ft.^{2} reserve basal area prescription.

Habitat Type	Timber value/acre	Total Costs/acre 100-mile haul	Total Costs/acre 200-mile haul	Net Returns/acre 100-mile haul	Net Returns/acre 200-mile haul
ABGR/CLUN	$6,438	$6,908	$7,863	-$469	-$1,424
THPL/ASCA	$9,012	$7,408	$8,512	$1,604	$501
THPL/CLUN	$9,057	$8,067	$9,255	$990	-$198
All Stands	$8,393	$7,636	$8,748	$757	-$355

DISCUSSION/MANAGEMENT IMPLICATIONS

The two prescriptions evaluated in this study provide suitable conditions for planted western white pine and western larch to gain a competitive advantage over naturally regenerating species, and provide a starting point for restoring western white pine where a rust-resistant seed source is limited or nonexistent. The height and diameter growth of both species is much greater through the first 20 years following treatment than for naturally regenerating species. The 35 $ft.^2$ prescription, because of the more open conditions it creates, allows for better diameter and height growth compared to the 75 $ft.^2$ prescription, as well as better survival of the planted trees. This does not mean, however, that the 35 $ft.^2$ prescription should be implemented in any stand where restoring western white pine is an objective. Rather, the prescription used should be matched to the site. For example, the 75 $ft.^2$ prescription may be a good alternative on exposed sites, such as south-facing slopes.

The two prescriptions were designed with the physiological needs of western white pine in mind, and do not represent a full range of prescriptions that may be used to restore western white pine. The goal of the 35 $ft.^2$ prescription was to provide western white pine with the free-to-grow condition of 92 percent visible sky specified by Jain et al. (2004). The 75 $ft.^2$ prescription was designed to approximate the 50 percent visible sky threshold where western white pine has a competitive advantage over other species (Jain et al. 2004). However, this analysis showed that the 75 $ft.^2$ prescription created conditions with 25 percent canopy cover and 75 percent visible sky—a visible sky level well above that needed for western white pine to gain a competitive advantage.

Treatments that leave moderately higher reserve basal areas may still provide western white pine with a competitive advantage over other species, but higher reserve basal areas will likely reduce the advantage of western white pine and western larch over other species.

Regardless of the prescription implemented, restoring western white-pine is a long-term process. Even though the prescriptions modeled in this study provide planted western white pine and western larch with an initial advantage over naturally regenerating species, these other species have higher densities 20 years after treatment. The naturally regenerating species have greater shade-tolerance than western white pine and western larch, and as the stands mature and the canopies close, these species will eventually comprise the majority of the stand. In order to sustain the initial advantage that the prescriptions provide for the planted western white pine and western larch, a cleaning should be conducted within the first 20 years of the stand's life to reduce the proportion of shade-tolerant trees. It is of utmost importance to maximize the survival of planted western white pine, because the planted pines of today are the seed source of tomorrow. Having a viable seed source of western white pine on the site dramatically increases a forest manager's options for restoring this species.

Blister rust is an important consideration in any effort to restore western white pine, as treatments that provide good conditions for white pine also provide good conditions for the alternate host. No data on *Ribes* populations were available for this study; therefore, the potential effects of blister rust on western white pine planted under the conditions created by these prescriptions are difficult to estimate.

The variability of resistance to blister rust in F_2 western white pine planting stock makes it difficult to model survival and mortality. In addition, growth rates of F_2 stock were assumed to be equal to unimproved (nonresistant) western white pine. As information concerning the survival and growth rates of F_2 stock becomes available from field trials, more refined estimates will be possible.

The harvesting system modeled in this study approximated a type of skyline system not typically used in the Inland Northwest. It included intermediate supports and an external yarding distance of 2700 feet, with an average yarding distance of 1800 feet. This system was chosen because of the lack of roads in the analysis area, and the likelihood that additional roads will not be built. In some cases it may be possible to use skyline systems more typically employed in the region, which have shorter yarding distances and lower operating costs.

Field tests of the two prescriptions modeled in this study would provide more reliable estimates of restoration treatment effects on western white pine, western larch, and naturally regenerating species. Such information would allow managers to modify the prescriptions as necessary to achieve optimum results. Cost estimates could also be refined by implementing these prescriptions in the field.

The loss of western white pine is not unique to the Middle-Black area, but is occurring throughout the Inland Northwest. The latest inventory of Idaho's forests (Brown and Chojnacky 1996) showed that western white pine was the only tree species in Idaho with negative net annual growth, i.e., mortality was greater than growth. Atkins et al. (1999) state that the number of plantings of western white pine have not been adequate to offset mortality in larger trees and naturally regenerating white pine. Without treatments to restore western white pine, other forest types will continue to expand (Atkins et al. 1999). The treatments proposed in this study provide a basis for restoring western white pine, and may be suitable elsewhere in the Inland Northwest, although further study would be needed to confirm their applicability to other areas.

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